

Transactions *of* The Chartered Surveyors' Institution

SESSION 1937-1938.

AT THE ORDINARY GENERAL MEETING

*Held at the Chartered Surveyors' Institution on Monday,
4th April, 1938.*

Mr. ROBERT COBB (President) in the Chair.

NEW MEMBERS.

The following new members were received by the
PRESIDENT prior to the meeting and signed the Register:—

Professional Associates :

BURLEY, LESLIE JAMES

MURRAY, FRANCIS A.

O'CONNOR, THOMAS FERGUS

PARKS, BENJAMIN NEWTON

SMITH, ROY CAMERON

WOOD, JOHN STEPHEN

A DISCUSSION took place on Mr. G. T. McCaw's paper entitled

THE BASIS OF MAP-MAKING : SURVEY OF CONTROL.

The PRESIDENT said that the Land Surveying Committee of the Institution had been re-organised to improve the status of land surveying all over the world. It was felt that the Colonies had rather relied on the Mother Country and the Mother Institution for a lead, which had not always been given to them, and the Land Surveying Committee had been organised with that end in view.

Those who had read the excellent article in the current issue of the *Estates Gazette* would have seen that land surveying was one of the oldest sciences that was known, and the Institution was very fortunate in having a paper presented on that subject by Mr. McCaw, whom he thought he could describe as one of the greatest living surveyors. Mr. McCaw had been good enough to undertake the honorary secretaryship of the Land Surveying Committee and was organising a great display of plans and books on surveying in one of the rooms of the Institution, which he was sure would be, when it was complete, something for the world to come and view.

Mr. McCaw, during the last forty years or so, had been interested in surveying all over the world. He had served on many committees, and he had surveyed in Ireland, Rhodesia, Sweden, Fiji and Uganda.

The Institution was fortunate in having present at the meeting that evening Sir Ernest Dowson, K.B.E. (Honorary Member); Brigadier Malcolm MacLeod, D.S.O., M.C. (Honorary Member), the Director-General of the Ordnance Survey Department; Brigadier H. St. J. L. Winterbotham, C.B., C.M.G., D.S.O. (Honorary Member), who was Brigadier MacLeod's predecessor in that office; Sir Montagu Sharpe, K.C., D.L., and Mr. Bocking (Chartered Surveyor).

Sir CHARLES BRESSEY, C.B. (Senior Vice-President), in proposing a vote of thanks to Mr. McCaw, said that, as the President had explained, the Council was extremely anxious to attract attention to a supremely interesting branch of surveying which perhaps had been rather neglected in the past, possibly because, although

supremely interesting, it was not supremely profitable in a commercial sense.

The members had seen from the slides shown by Mr. McCaw the labour that was involved in carrying out the Ordnance survey. What it must have been before the invention of light compact instruments it was difficult to conceive. The Tavistock theodolite had a 5-inch circle, whereas the theodolite used in the very early days, he believed, had a 36-inch circle. He would ask the members to imagine Mr. McCaw clambering up a cliff wearing the 36-inch circle of a theodolite round his neck. To-day, with the theodolite of 5-inch circle, such a feat presented no difficulty. He believed he was right in saying that the 5-inch theodolites now in use would give a micrometer reading to half a second, which was an instance of the extraordinary accuracy now obtainable by the instrument makers.

Mr. McCaw was, of course, being used as a decoy on the present occasion, in the hope of interesting the younger generation in the very fascinating branch of science with which the paper dealt. It had fascinated the best minds for two or three thousand years past ; Mr. McCaw played a very prominent part in that succession of enthusiasts. What had always struck Sir Charles with surprise and pleasure was the extraordinary cheerfulness of the gentlemen who specialised in that sort of work—Mr. McCaw, for instance. Yet geodesy had been one long series of disappointments, disillusionments and surprises to everyone who had ever touched it. It began with the delightfully simple conception of the world as a flat disc with the ocean circulating round the rim and with Jerusalem in the middle of the disc. If Mr. McCaw had read a paper 2,500 years ago he would have told his audience all about that and exactly how it worked! Then that idea had to be abandoned, and cartographers started the wheel map, in which the continents and seas were all neatly tucked away between the spokes—another attempt to realise the conception of tidiness and symmetry! Then the Greeks came with the perfect sphere, and after that had been used for some time it was found that our globe was not a perfect sphere but was extremely flattened at the poles. Then, when the revolutions of the world were studied it was found that it did not revolve true to standard at all, and constant recourse was necessary to compromises, adjustments and corrections in the attempt to reduce the world to some sort of regular figure and regular movement. Disappointment always awaited the gentlemen who undertook that particular task, yet they came up smiling, and they were entitled to very great credit for what they had done. He believed that some of the minor irregularities of the earth's shape and movement still defied analysis, but he was quite sure that Mr. McCaw would continue

his work and would ultimately succeed in giving people what they wanted, *i.e.*, an earth the shape of which could be simply defined and which could be used for the production and sale of reliable Ordnance sheets on a profitable basis by the Ordnance Survey Department.

Mr. T. G. BOCKING (Chartered Surveyor) said he considered it an honour to be asked to second the vote of thanks, and he did so with very great pleasure indeed. He met Mr. McCaw in 1935, when the Empire Survey Conference was held in London and other parts of the country. Mr. McCaw was, he believed, the Secretary of that Conference, and his energy and skill showed what manner of man he was. He himself had been a delegate to that Conference, and he believed that the Chartered Surveyors' Institution had also sent delegates to it. Perhaps that had had some bearing upon the creation of the new outlook on surveying. He himself happened to be a mine surveyor. Mine surveyors had been included within the Institution a number of years ago, but he thought that even then the Institution did not look upon them as measurers but as valuers.

He had been very interested in the historical opening of Mr. McCaw's paper. It added a human interest to the subject, and showed that there were men in the past who did something in surveying. They established permanent stations in the fields of time.

He was fascinated by a word used by Mr. McCaw in the printed paper, which he hoped all the members had read, *i.e.*, "rope-stretcher," or, as the Greeks called it, "*harpedonaptēs*." That reminded him of a name which mine surveyors had been called—"latchers." That was not a colloquialism, he was sure, because in many mining leases the lessor had the right to "dial " and latch " the workings. He had been trying to find out from his older friends what was the origin of the word "latcher," but he had not been successful in that. He had a lurking suspicion that it had something to do with rope-stretching (there were the words "lace" and "latch") and was linked up with the old Greek "rope-stretcher." He hoped to pursue his researches in that direction a little further. The Prophet Ezekiel, who ought to be called the prophet of surveyors, wrote three chapters of survey notes (Chapters 40, 41 and 42), and the surveyor there used a line of flax and also a reed, which appeared to be about the same length as the Roman rod to which Mr. McCaw had referred. That man was a rope-stretcher, he thought, and in Chapter 47 it was related how he took his line through floods of water, measuring some 3,000 cubits therewith. There were other

names for measurers nowadays, such as "chain-men." It was curious that one did not find many surnames associated with surveying.

Jerusalem had been mentioned that evening. The survey notes which were found in the Book of Ezekiel were used, he believed, some centuries later to re-establish the Temple at Jerusalem, and it was a curious fact that in the Book of the Revelation the New Jerusalem was described as being four-square. It must not be forgotten that that was written in Roman times. It was rather a large square, over 850 miles, which would take some setting out by human agency, but it seemed to him quite remarkable that one of the principal features was that it was four-square.

With regard to mine surveying, he had in his office a copy of the second edition (1845) of a book by John Budge called *The Practical Miner's Guide*, in which it was said that at that date in Cornwall there were no surveys which were calculated trigonometrically. It might be thought that gridding was a modern contrivance, but the author of that book advocated that the paper on which his new system of surveys was plotted should be marked in 2-inch squares.

Reference had been made to the Ordnance Survey and the use that was made of it. Mine surveyors had made their own surveys, and had only recently awakened to the fact that they could, by suitable correlation with the Ordnance Survey, use their work, which for mine plans they had previously somewhat ignored.

The *groma* was a fascinating instrument to the mine surveyor. The system of the *groma*—that was to say, setting out by lines—was used to set out and to continue straight many miles of underground roads in this country. There was in fact hardly any other method of prolonging a line, and sometimes also the only means of correlating surface and underground surveys was by using two wires hung in a single shaft, the prolongation of those lines being the sole means of correlation between the surface and underground. He could not help thinking that the old Romans had an excellent means of lining out with the *groma* which they used.

Reference had been made to the yard land. Quite recently he had had occasion to try to find out in Warwickshire how many acres a yard land represented. The acreage of the total area was given (76 yard lands=2,613a., Or., 20p.), and he calculated the yard land to be about $34\frac{1}{2}$ acres. The Roman *actus* mentioned in the paper was 31.284 acres. The yard land in England, he believed, varied from 15 to 40 acres, but in Warwickshire it seemed to be near to the Roman *actus*.

He had always been a great believer in traversing. Mr. McCaw said in his paper that precise traversing was as accurate as secondary triangulation. Mine surveyors had to believe that; they

had no other means of surveying underground. They could not look through a coal face or a rock wall, and they had to rely upon very lengthy traverses. It was extraordinarily interesting to him to find that, at long last, traversing was regarded as a very accurate means of surveying. Mine surveyors often had to rely upon long lengths of survey lines which they could not possibly check except by coming back, which he did not think was really worth while. One found that, in traversing, the measurer came back into his own; and did not it seem from the pictures which Mr. McCaw had shown on the screen that the key to the accuracy of surveying—the triangulation and the survey itself—was in measuring almost as much as in the instrumental work? His own feeling had been for a long time that if his measurers did their work properly he had no need to fear as to the result; but if one could not trust one's measurers, then one's own work was no good, and he thought that should be borne in mind by all surveyors. The younger men were usually given the rope-stretching to do, but he suggested they should remember that that work was as important as that of the man who had to look after the instruments.

Brigadier H. St. J. L. WINTERBOTHAM, C.B., C.M.G., D.S.O. (Honorary Member), said that Mr. McCaw had refrained from saying how much his own ideas had come into the pictures that he had shown that evening. For example, the tripods which had been used recently in the measurement of the new base were Mr. McCaw's own design and were first used for a base in Uganda. Mr. McCaw had said that a Roman surveyor became Governor of London. That was a habit that the British Empire had not sufficiently acquired, although of recent times a surveyor had been the Governor of Cyprus, and a very famous surveyor, Sir Gordon Guggisberg, had been Governor of the Gold Coast. He thought that the practice might go further.

With regard to the Latin phrases used, he would like to ask Mr. McCaw what the word "*bottontinus*" came from and what it meant. Mr. McCaw had also used the word "*saltus*," which he remembered meeting in a different context, and he would like to know exactly what survey meaning it had.

He would also like to test Mr. McCaw on Shakespeare. It would be remembered that in *King Henry VI*. Jack Cade struck his staff on London Stone and said: "Now is Mortimer lord of 'this city.'" Had that stone anything to do with the Roman survey which Mr. McCaw had illustrated? He did not feel at all sure that it had not.

He had been very glad to hear Mr. Bocking speak about the

grid with some disrespect for those who considered it to be a modern invention. It was modern only as far as the name was concerned, and he was afraid that he was the culprit, because he used the word "grid" first to translate the German "*gitternetz* . . ." during the War; it seemed to be the only appropriate translation. But as a survey convenience Mr. McCaw had lifted it out of the present unruly times and had given it an honourable and ancient derivation. The Ordnance Survey had used it almost from the beginning. The members might recollect that, when Colby had finished the survey of Ireland and was entrusted with a 6-inch survey of the more important northern counties of England, he laid down a system of co-ordinate squares. The *cardo maximus* in every case was the county meridian. Then the county was split up into rectangles of 6 miles by 4, which constituted a full 6-inch sheet. Then it was found easier to reproduce the 6-inch in the quarter sheets, 3 miles by 2. The grid was shrinking. Then came the 25-inch survey, and that split up each quarter 6-inch sheet into four 25-inch sheets, the grid being then $1\frac{1}{2}$ miles by 1 mile. Then, firstly for the examination of the plotted work, and, secondly for its revision, each 25-inch sheet was split up into six tracings, so that one got down to a $\frac{1}{2}$ -mile grid, which covered the country. A grid in that sense was a cartographic matter rather than a matter of control. It was a convenience in mapping, and its essential point was that, if it was put upon the paper at the time when the map was plotted, any shrinkage or expansion of the paper itself was witnessed to by the grid.

With regard to the revision of Ordnance Survey maps, one came back to the *groma*, which embodied the very simple fundamental principle of working by "straights" and "prolongations" on which the revision of Ordnance Survey maps had always been carried out, to the complete scandalisation of all foreign surveyors, but to the complete benefit of the British nation.

The grid, of course, had a number of other uses. For example, in the computation of surveys it was possible to use the grid so as to compute where the observed rays were going. One could then make graphs of the positions of points as intersected by those observed rays, and so, by eye, choose the mean or "most probable" spot. That small semigraphic solution had been described in 1856 by one of the finest computers that the Ordnance Survey had ever had. Mr. McCaw had referred to the inordinate length of time which the first trigonometrical survey of England took. Mudge and Colby had twenty-five men at work in England on the 1-inch survey, and but one or two other officers, and, with that little party, started upon the 1-inch concurrently with the great triangulation of England. Colby was one of those men who

were perpetually being wanted by the Royal Society and other learned bodies. The reason why it took so long to get the triangulation through was that there were only about two or three officers available for the whole work of the Ordnance Survey, and they had to do the work with their own hands.

He wished to thank Mr. McCaw very warmly for a most admirable paper.

Brigadier MALCOLM MACLEOD, D.S.O., M.C. (Honorary Member), Director-General, Ordnance Survey, said that not only had Colby had the difficulties to which Brigadier Winterbotham referred, but he thought it was correct to say that Colby had had to invent his own methods as he went along. He did not think that, in the circumstances, the time taken over the original triangulation should be regarded as too long; in fact he thought it was really very short.

He was much interested in the marks which the Romans left for their surveys. In the revision of the Ordnance Survey it had been found rather embarrassing to have no easily accessible permanent survey marks. The old triangulation stations of the Ordnance Survey were marked by stones buried in the ground, and the descriptions were often very inadequate, such as "The stone is in Mrs. Smith's backyard, and she will tell you where it is." That description would not last for a hundred years.

It had been considered advisable to mark the new primary and secondary stations with concrete pillars about 4 feet high. A number of people did not like having a concrete pillar even of that size on their property, and he wished some of those had been present that evening to see the marks that the Romans put up over their stations; they might then agree that they were being let off very lightly. He could only hope that the concrete pillars would prove as permanent as the marks which the Romans used for their survey.

With regard to the measurement of the base, the Ordnance Survey officers had had more adventures than those which Mr. McCaw mentioned. Not only had they had to punch a hole through a barn, but on one occasion they missed an oak tree, about 3 or 4 feet in diameter, by 3 inches. In the place shown in one of the photographs that Mr. McCaw had put on the screen it had been necessary to cross a main road with a great deal of traffic on it. The co-operation of the police had been obtained, and at the appropriate time they had held up all passing motorists to look at their driving licences!

One point which had emerged from the new triangulation was that it seemed as though theodolites had now reached the limit

of accuracy. An analysis of the results of the observations on the new primary work seemed to indicate that the principal source of inaccuracy in observation was not in the instrument ; it was not in gradation or pointing, but was very largely a matter of horizontal refraction. In the vertical plane a visual ray was bent by variations in density in the atmosphere, and it had long been suspected that something of the same sort might occur in the horizontal plane when one got a ray grazing or nearly grazing over a sloping piece of ground. Fairly clear evidence had been obtained that that happened in some cases, and it seemed now that it was not worth while attempting to get greater accuracy in theodolites.

With regard to the grid systems, they had been revived during the War, and they had then been put, he thought, to a number of new uses. In particular they were used for map reference—*i.e.*, for indicating the position of points, and that, he thought, was a new use which was likely to be very important and was one which civilian surveyors would be wise to study or, at any rate, to become acquainted with fairly soon. The soldier now regarded a grid as an indispensable feature of a military map, so useful had it proved to be in the War. He could not but think that, if that was the experience of the soldier, it would be paralleled by the civilian, and that grids would be useful not only to the surveyor, but also to the private individual, when they knew how to take advantage of them. That would introduce surveyors to a whole range of new problems, on which he would not venture to touch that evening.

Sir ERNEST MACLEOD DOWSON, K.B.E. (Hon. Member), said he knew very little about the subject with which the paper dealt, but he would like to congratulate the Institution firstly on the subject-matter, and secondly on the particularly interesting historical foundation which had been given to what he might speak of perhaps as the Institution's new development. People were always impressed by historical matters, and if they could found their knowledge upon past history they felt that they were getting on to a steady and sound basis. He congratulated the Institution and Mr. McCaw on a most extraordinarily interesting paper.

Sir MONTAGU SHARPE, K.C., D.L. (Visitor), said he had come to the meeting to listen, and had not expected to be asked to say a few words, but he did so with very much pleasure, because he had had a little to do with the investigation of the Roman survey of Britain. The map of the Middlesex area which Mr. McCaw

had shown had taken him about fifteen years to complete. Wherever one went in England—York, the Isle of Wight, Colchester, &c.—one found through the *compita* the Roman squares, but he himself had not sufficient local knowledge to be able to point to the *bottontini* and stones which the Romans had used. His own county of Middlesex, however, he knew very well, and so he could point out where the stones and mounds were situated. If anyone took a motor car along the Bath Road and stopped at the new county bridge at Cranford and looked to the right, he would see one of the mounds, which was a very good specimen. He was sorry to say that the fir trees at the top of it had recently been cut down, but he was going to induce the Middlesex Archæological Society to have that *bottontinus* opened, in order to see where the charcoal, &c., had been buried. Only the other day he found that someone had delved into a mound at Ruislip. He knew what had been found there, and a good deal of broken crockery had been unearthed, which was one of the things which the Romans buried in these mounds. When there was any dispute as to these mounds, if such things were found inside them, it proved that they were surveyors' mounds and not burial *tumuli*.

He could assure the members that the subject was a most interesting one. His antiquarian friends went in for what he called spectacular antiquarianism; they gave a great deal of information about Roman walls, villas and tessellated pavements, and so on, but he thought that enough had now been heard about such things, and that attention should be devoted to finding out how the Romans in Britain lived, how they worked the land, and what were their customs and ways. The newspapers to-day were full of articles dealing with the promotion of agriculture, and the Romans also had been interested in agriculture. He very much regretted that the subject of Roman rural economy had not been studied in this country, and he hoped that some of the members of the Institution would take an interest in that subject and promote it.

Mr. T. EASTWOOD (Visitor; Geological Survey) said that the amount of actual surveying done by the Geological Survey was very small indeed, and, like a good many other surveyors, they had to depend almost entirely on the Ordnance Survey for the real basis of their work. He and his colleagues had listened with great interest to the paper, and he wished to thank the President and members of the Institution for the invitation to attend the meeting.

Colonel H. C. COLE, C.B.E. (Vice-President), said that the resuscitation of interest in surveying proper by the Institution to

some extent arose from a meeting of the International Federation of Surveyors, of which he had the honour to be president. He was afraid that Brigadier Winterbotham, who had attended many of the meetings of the Federation, was inclined to scoff at the way in which some countries carried out their surveys, but some of them were only small countries and some were almost in the Dark Ages as far as surveying was concerned. Two years ago he had had the pleasure of an interview in the Balkans with the Director of their Ordnance Survey, and they went over the whole of the work which was done there. The Director explained how very difficult the work was for him, because when he took it over the survey was a hotchpotch of Austrian, Serbian, Montenegrin, Arabian, some Italian and a good deal of Turkish triangulation, with the result that a certain well-known town in Serbia was about 5·7 kilometres out of position when he took over. He imagined that even the Romans, with their methods which to-day seemed rather amateur, could not have made such a mistake as that. The International Federation of Surveyors had been trying to help by obtaining information as to how various scientific matters were dealt with in this and other more enlightened countries, and sending that information to surveyors in other countries who had not the advantage of having all their plans provided for them by the Ordnance Survey. In his own office he thought as many plans were used as anywhere else. They telephoned to Southampton at 4 o'clock in the afternoon, and the most beautiful set of plans arrived next morning. They even went to the Ordnance Survey for mining surveys, but he believed that the Ordnance Survey found the same difficulties in correlating the mining survey underground with the surface as had been referred to by Mr. Bocking. He believed that the Ordnance Survey had only recently undertaken mining surveys, but they had produced excellent results for his department in an incredibly short time.

He wished to thank Mr. McCaw for his paper and also the speakers in the discussion, who were engaged in various walks of life closely allied to surveying, for their attendance and the remarks they had made.

The vote of thanks was carried by acclamation.

Mr. G. T. McCaw briefly acknowledged the vote of thanks, and said he would reply in writing to the questions which had been asked.

The following written reply has been received from Mr. G. T. McCaw:—

Were I to attempt to respond duly to the generous remarks of the proposer and seconder, I fear that I should fail sadly to give proper attention to the numerous matters of interest which have been raised. It is possible that there are few who have not asked themselves the question, charmingly posed by Sir Charles Bressey, implicitly, What should I have thought on the subject had I lived 2,500 years ago? Some surveyors in the course of their reading may have seen references to the "Ordnance Survey of Jerusalem." In the presence of authorities on a city twice mentioned to-night I think that it would be well for me to adopt the ancient policy of non-committal on all these questions.

It is certainly true, as Mr. Bocking has said, that few survey methods and instruments have become known by surnames; but there are exceptions—the Gunter chain, for example. The most interesting exception, perhaps, is the *Pelorus*—an instrument used in the Navy for fixing bearings. This took its name from the north-east promontory of Sicily, itself named after a pilot by a Carthaginian general, who was filled with remorse for his unjust condemnation of the man whom he had suspected of drawing his fleet into Scylla or Carybdis. In South Africa a case of the problem of simple resection used to be known as a *Snellius*, though actually the problem, as Delambre showed, dates back to Hipparchus. Again, some may be acquainted with the "*Beamanare*," used in tachymetry, and the Everest theodolite, now obsolete, may also be mentioned.

The O.E.D. does not help much with the interesting old use of "latching" for chaining. To latch may mean to grasp with the hand as well as to lace; both notions may be combined in "latching," particularly if the chain was fitted with rings which were fastened to hooks on training poles, repetition of action being conveyed by the idea of lacing. Moreover, the fingers and arm may well replace the hook and pole.

It is very pleasing to have another reference to the *yardlands* from Mr. Bocking. One may follow through the ages the equation: Roman *centuria* (strigation or scamnation) = Saxon *virgate* = English *yardland* = 32.5 acres gross or 31.3 acres nett, it being remembered that *virga* (rod) is the Latin form of the English yard. Four *virgates* made one hide or carucate of standard area.

Brigadier Winterbotham has asked some pertinent questions, some of which are beyond my range. It is just as well to be careful, for over fifty years ago an attempted derivation of *bottontinus* clearly did not meet with the approval of the then

President. *Saltus* was originally the glade in the forest where Macaulay's laughing girls were wont to besport themselves; it is to be hoped that in the days of Plautus they were not too sophisticated to favour Nature's carpet. But for the meaning of "Coldharbour," whereof there are 143 in England, for the unhappy history of Oswulf's Stone in Hyde Park, and for a multitude of facts of the highest interest to a knowledge of life in British, Roman and Saxon times, surveyors should consult the two unique volumes written by Sir Montagu Sharpe. With their thoroughness the Romans had the boundary stones brought from a distance, so that they could not be mistaken for the rock of the country-side. Some day we may hope to see the history of the old triangulation of Great Britain and Ireland told by Brigadier Winterbotham; there will then be a fuller appreciation of the work of the Ordnance surveyors of 100 years ago, whose achievements I have acclaimed on more than one occasion. In giving us the sample word "grid" he banished some awkward pre-War terminology.

There is no surveyor who will not sympathise with the Director-General in his efforts to make marks permanent. The Romans placed them under the care of *Termirvus*, one of the deities worshipped in the village *compita*. Moreover, during the *compitalia* the settlers beat the bounds, starting the custom which later developed into the Rogation-tide processions. The removal of a survey mark was thus an offence against the gods, punishable with death. Dr. de Caterini gives a Roman example of a direct imprecation against the destruction of the neighbour's landmark. A pillar stands in Italy to this day bearing the inscription: "QUISQVIS HOC SVSTVLERIT AVT IVSSERIT VLTIMVS SVORVM MORIATVR." The most interesting word in this malediction is *jusserit*, which appears to mean "shall claim by process of law"; so that even the law was brought within its terms. At some future date we hope that Brigadier MacLeod will tell of the amusing incidents which occurred in the course of the work of his officers in establishing indefeasible national beacons for the guidance of surveyors. The Saxons destroyed much of the Roman system. It is to be hoped that a race of later iconoclasts will not break up the new work in the Balkans to which Colonel Cole refers.

It will have been obvious to all readers that in the absence of the work of Sir Montagu Sharpe the subject of the paper discussed would have lost a very large proportion of its value. We feel that we cannot be too grateful to him. His story of the cannon at the western end of the Hounslow Heath base is delightful. That at the eastern end of the same base, standing in a nursery at Hampton, also carried its myths, which, being very diverse, had the merit of being all doubtful. One was that the cannon was put there to indicate the height of St. Paul's. At a short ceremony some

years ago Brigadier E. M. Jack, then D.G.O.S., paid a fitting tribute to his famous predecessor General Roy, and a bronze plaque now surmounts the great bronze cannon—one of the most permanent marks ever constructed.

In conclusion the writer would like to thank members very cordially for their kind reception of his paper.

Note.—The unit adopted, which may be too great by $1/1200$, makes the *jugerum* = 0.62568 statute acre very little over five-eighths. The Royal *arpent* is 1.26204 statute acre, a little over 2 *jugera*. It appears to be Sir Montagu Sharpe's "customary" acre, and is ploughland based on a perch of 22 French feet, the common French perch having 20. But this does not appear to be the *arpent* of Domesday Book.

PAPER 584.

THE PREVENTION OF VIBRATION IN BUILDINGS.

By Mr. J. Francis Smith, F.R.I.B.A. (Chartered Surveyor).

Paper to be discussed at the Ordinary General Meeting of the Chartered Surveyors' Institution on Monday, 9th May, 1938. Illustrated by lantern slides.

INTRODUCTION.

The surveyor is nowadays frequently faced with the problem of vibration in buildings, whether he be a building surveyor, quantity surveyor, or a member of the branches of the profession dealing with the management of property. While the problem is, in the final stages, within the province of the engineer, it is obvious that surveyors should have some knowledge of the methods which can be adopted to mitigate the trouble of transmitted vibration, and it is the purpose of this paper to enunciate the general principles of the isolation of buildings from the effects of vibration.

Sound insulation and acoustics are closely allied to our subject, but they have been excluded from the present text in order to limit the scope of the paper to a sphere which is often overlooked and about which too little co-ordinated information is available. Engineers have been engaged upon the practical solution of vibration problems for many years, and there is a tremendous amount of published information upon the theoretical aspects of such work.

There is, however, no book published in the English language which is exclusively devoted to practical vibration isolation.

As to whether buildings generally are likely to be seriously

affected by normal vibration,⁽¹⁾ it can be stated that the conditions arising in buildings on a good subsoil are unlikely to have effect upon the structure, whether these vibrations are caused by machinery running in the building or are imposed by external traffic sources.

It must not be assumed from this statement that vibrations *cannot* have effect upon the structure, since numerous cases can be cited where vibration has resulted in a compacting of the sub-soil, and so caused settlement to occur. Vibrations have also been responsible for the cracking of plaster ceilings.

The reason that vibration assumes a serious aspect is that human sensibility is such that vibration in buildings may become unbearable long before the structure is affected.

The surveying and architectural professions could do much to assist the work of engineers in connection with the buildings over which they have control.

On the other hand, it is noteworthy that the makers of machinery usually volunteer little or no data about the unbalanced forces in the machines they supply and that much machine foundation design is empirical.

Inasmuch as practically all forms of machinery have been successfully isolated from the building in which they are situated, it is the duty of the members of our profession who are responsible for the design, erection and maintenance of buildings to see that machinery is so isolated that there is no possibility of it becoming a source of nuisance.

The present paper is not a mathematical treatise, but merely sets out to describe the nature of vibration problems, and must necessarily traverse certain ground which may be considered somewhat elementary.

THE NATURE OF VIBRATION.

In order to appreciate the nature of vibration, it is best to consider the example of, say, a spring to which a weight is attached, the weight being set in motion in a vertical

⁽¹⁾ D.S.I.R.: Report of the Building Research Station, 1937. (H.M. Stationery Office.)

direction. The cycle of changes through which the weight passes may be illustrated by the time displacement curve given in Figure 1, which is simply a graphical representation of simple harmonic motion.

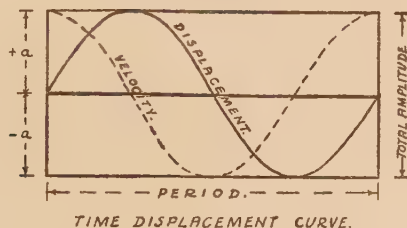


FIG. 1.

The range of movement of the weight on either side of the mean position is referred to as the *amplitude* of the vibration, and in the present paper may be taken to represent the actual distance travelled above or below the horizontal mean position.

The time taken to complete one cycle is referred to as the *period*, and the number of vibrations which take place in a given unit of time, the *frequency* of vibration. This unit is usually given in seconds or minutes, and where the second is used as a unit of time, the expression " hertz " is often interchanged for the words " cycles per second."

The system under consideration, if set in motion, will continue to vibrate at a frequency which depends upon the characteristics of the spring and the amount of the weight. The number of free vibrations taking place within the given unit of time is referred to as the *natural frequency*.

The weight will be brought to rest by the action of air friction and the dissipation of energy within the spring, and this process is known as the *damping* of vibration. Damping is very small in the case of a spring, but if it is imagined that a piston is attached to the bottom of the weight and that this piston works in a cylinder of water or oil, it is obvious that the damping of vibration would show a rapid diminution in amplitude in each successive period (Fig. 2). In the case of such a high degree of damping, the natural

frequency is altered slightly, but by a very small percentage, and one can afford to neglect the change in frequency in calculations.

Another important factor in all vibration problems is that of *resonance*. If two vibrating systems have the same frequency and are mechanically connected, a state of

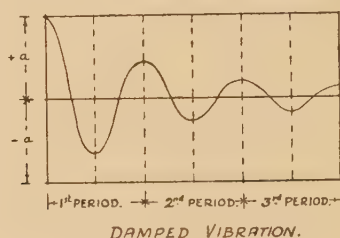


FIG. 2.

resonance is said to exist. Thus, if the natural frequency of the floor of a building is the same frequency as, say, incoming traffic vibrations reaching it through the structure, the effect of such resonance will be to cause a noticeable increase in the amplitude.

THE SPHERES OF SENSIBILITY.

It follows from the opening paragraphs that the primary problem is to establish criteria of susceptibility of human beings, since if adequate protection is provided against this range of nuisance, the building can generally be regarded as structurally safe.

Experimental investigation started as far back as 1875, and following valuable work done in several countries, Professors H. Reiher and F. J. Meister conducted an exhaustive series of experiments, the results of which are now generally accepted as reliable criteria of the spheres of susceptibility. The brief description which follows is based on the published results of the tests.⁽²⁾

⁽²⁾ H. Reiher and F. J. Meister: *Die Empfindlichkeit des Menschen gegen Erschütterungen. Forschung auf dem Gebiete des Ingenieurwesens.* (Band 2, No. 11, Nov., 1931.)

The experiments were the outcome of a theory that since the reaction of normal human beings to noise produces fairly uniform results, it was logical to suppose that the reaction to vibration could be similarly plotted. Accordingly, a selected number of persons were submitted to the effects of sinusoidal vibrations which were imposed on their bodies when in vertical and recumbent positions. The range of frequencies chosen was between 3 and 70 hertz, which is the range of frequencies for traffic and industrial vibration, and the amplitude of these vibrations ranged between $\cdot 0001$ cm. and 1 cm. The apparatus consisted of a rectangular platform mounted in an angle iron frame using flat coach springs in such a manner that both horizontal and vertical vibrations could be imposed. Noise was reduced to a minimum so that it should not affect the results of the experiment. The exciting force was imparted by an unbalanced flywheel, mounted on the platform and driven at an appropriate speed. Both amplitudes and frequencies were carefully checked. Special watertanks were provided in order to balance the platform when the persons were upon it.

The effect on ten persons, differing both in physique and occupation, were examined, their ages ranging from 27 to 30 years. Each person was submitted to tests lasting five minutes, and about 1,000 actual tests were made. The personal reactions were then classified into one of the following groups:—

- (0) Vibration imperceptible.
- (1) Vibration just perceptible.
- (2) Vibration distinctly perceptible.
- (3) Strongly perceptible.
- (4) Uncomfortable.
- (5) Very uncomfortable.

The border line between (0) and (1) can be regarded as the *threshold of sensibility*, and that between (3) and (4) as the *threshold of danger*. Spheres (1) to (3) are accepted as

bearable and not detrimental to health, and (4) and (5) may be dangerous to health.

When each of the personal reactions thus experienced were graphed on a logarithmic basis with frequency plotted against amplitude, the results fell into well-defined groups. The limiting lines of sensibility are shown on a specimen of this type of graph (Fig. 3).

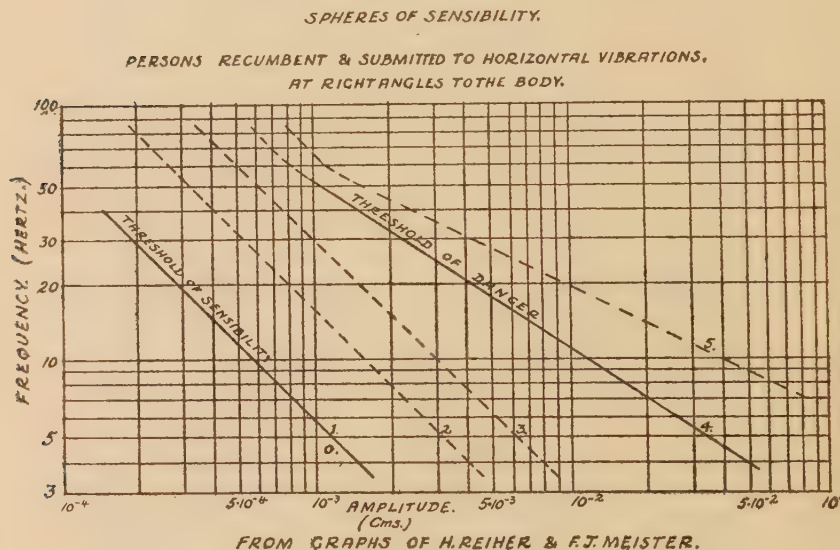


FIG. 3.

The following facts were also deduced as a result of these experiments:—

1. That the greatest discomfort is felt by persons in a recumbent position subjected to the effect of horizontal vibrations at right angles to the body.

2. That the least sensitive position is that where a person is lying on the back and exposed to vertical vibrations.

3. That one person was affected by a certain frequency, which caused dizziness, and that this effect was not apparent when the vibrational stimulus was slightly above or below this frequency.

This point seems to bear out a theory which has been advanced that certain persons are capable of responding to the effects of resonance. The results of the tests can be taken as a satisfactory indication of human reaction to vibration, and the graphs are, in fact, used in Court cases on the Continent, but I am not aware that they have ever been used for cases in this country.

Finally, it was established that the curves follow the mathematical law $a \times n^k = c$, in which a = amplitude and n = frequency.

k and c are, of course, determined from the curves.

Up to the time of these tests opinions differed upon whether the criterion of sensibility was dependent upon velocity, that is, the actual space travelled through in a given time by the person subjected to the vibration, or was dependent upon the acceleration, that is, changing velocity.

The tests established that the velocity remains constant for all frequencies and amplitudes in the first sphere, the exponent k being unity, but in the other spheres the value of k becomes greater. It would therefore appear that the principal criterion of sensibility is velocity in the lower ranges of feeling, and that acceleration and changing acceleration affect the sensibility as we approach the threshold of danger.

The curves, it must be emphasised, are drawn for sinusoidal vibrations, that is to say, simple harmonic motion, and in the case of non-harmonic vibrations it would be necessary to apply harmonic analysis to any record before the appropriate disturbing frequency could be inserted into the graphs ; but since much normal vibration is not far removed from the sinusoidal form, it is usually possible to classify the results of vibrograph measurements without recourse to such analysis.

MEASURING INSTRUMENTS.

Having established some reliable data about the degrees of sensibility, it is next essential to turn our attention to the instruments which may be used for measuring the

amplitude and frequency of vibration, both in horizontal and vertical direction.

For practical purposes it is usual to make use of a mechanical recording instrument, which may be called a vibrometer or vibrograph. Various types are available, but only those which produce a permanent record are of much practical value. Such instruments usually take the form of a seismograph when used in connection with building vibrations, and one well-known type records the vibrations on a strip of celluloid through the operation of a stylus. At the same time, a second stylus, connected to a time-recording device, marks the celluloid strip at 1-10th second intervals, thus enabling frequencies to be determined.

These records can be magnified by a photographic process to any desired extent, and can then be readily examined and, if necessary, analysed.

One instance will serve to show how a vibrograph can immediately help in the solution of problems even before the results obtained from the record are applied to Reihel and Meister curves.

If buildings are affected by forced vibrations, resonance may be set up in some part of the structure. The record of forced vibrations may be non-harmonic and a complicated curve, but as soon as resonance enters, the curve at once changes to purely sinusoidal form.

If we assume that a machine is the cause of this resonance, it is quite possible that by slightly altering the running speed of the machine, a small amount (5 to 10 revolutions per minute), its sphere of resonance will be avoided, and the trouble cured.

PRACTICAL BUILDING ISOLATION FROM TRAFFIC VIBRATION.

There is no published record of any large-scale examination of the problem of traffic vibrations carried out on buildings in this country, but in 1931-1932, under the auspices of the Heinrich-Hertz Institute,⁽³⁾ very careful

⁽³⁾ W. Hort, G. Mensch and H. Waas: *Sicherung des Bürohauses der Rhenania-Ossag in Berlin gegen Verkehrerschütterungen*. "Die Bautechnik," 1932 (Heft 10).

investigation was made in Germany in connection with the building of Shell House in Berlin. Measurements were taken by means of a seismograph when the site was excavated, and the results of these measurements indicated the possibility of considerable incoming vibration. Accordingly steps were taken to design the building so that an air space was contrived between the retaining walls on all sides of the building and the main structure, to protect the building from the effects of traffic vibration.

In addition to this, the whole building stands upon a concrete raft having a minimum thickness of about 3 feet.

As soon as the carcase of the building was completed in 1931, a large-scale test was embarked upon, using as the source of disturbance a special wagon which made circuits of the building in the early hours of the morning. Measurements were made with a three-component seismograph having optical registration, and a second seismograph was set up in a permanent position to make certain that the vibrations imparted by the moving lorry were reasonably uniform for each run taken during the tests.

Two prevailing ranges of frequencies were found to exist for the vertical and horizontal measurements. These were between 9 and 12 hertz and 11 and 22 hertz respectively, and by plotting the amplitude registered on each floor the total effect throughout the height of the building was established. In the case of the horizontal component, the magnitude was nearly constant over the height and lay between 2μ and 4μ ($1\mu = 0.001$ mm.). The vertical component, however, increased with the height quite substantially in the lower range of frequency, being of the order of 2.5μ on the sole plate and 10μ on the ninth storey.

A clear case of the effects of resonance was established in the case of the higher range of frequencies and occurred on the third floor. At this level materials had been piled on the floor, thus reducing its natural frequency and bringing it within the range of resonance.

A further series of measurements taken along the sole plate in the basement showed diminution in the amplitude of the vertical component and a very considerable improvement

in respect of the horizontal component when they were compared with the measurements taken outside the building.

The efficiency of the air gap construction was investigated by comparing the vibration of the solid pavement externally with the vibrations measured internally. As may be expected, the efficiency of this method of isolating buildings is more noticeable in the case of the horizontal than the vertical vibrations.

The construction used unquestionably places the amount of disturbance into the lower spheres of the Reihher and Meister curves, and for this reason is to be commended.

GENERAL CONCLUSIONS.

The principal factors which influence the transmission of external vibration to the carcasses of buildings may be considered under the following headings:—

- (a) The sub-soil conditions.
- (b) The street and traffic conditions.
- (c) Design and construction of the building and the use of isolating materials.

Under the first section normal building sub-soils can roughly be classified as rock, chalk, clay, sand and gravel.

Both rock and chalk transmit vibration readily and have a partiality for the higher frequencies. Clay and sand, on the other hand, are chiefly affected by the lower frequencies, and particularly so if wet.

The best building soil for the minimisation of the effects of vibration is undoubtedly firm dry gravel.

A waterlogged sub-soil demands special precautions against the transmission of vibration, and in the case of Shell House previously described, which stands near the banks of the canal, the high-ground water level influenced the design of the foundations.

The ideal conditions in regard to streets, are, of course, smooth surfaces and the absence of uneven expansion joints across the road.

Pavement and paving stones may be separated from the face of the building with some form of elastic joint, and for the reasons previously given, adequate sub-soil drainage is desirable.

It is of interest to note that the magnitude of vibrations caused by solid or metal-tyred vehicles is directly proportional to the speed up to 20 miles an hour, and that pneumatic tyres have been found to effect a reduction of about one-third of the original amplitude registered when the vehicles were solid tyred.

Buildings should be designed to have a low natural frequency with foundations taken to as great a depth as possible, having regard to the nature of the sub-soil. To this end the use of a massive sole plate and retaining wall to provide the inertia so desirable at the base of the building is a fundamental principle.

It is a valuable practice to introduce through vertical joints between those parts of the building which are of unequal height, particularly on soils which may be subject to unequal settlement and where the raft type of foundation is impracticable. Those parts of the building which contain machinery, and the services could be successfully isolated by means of complete vertical severance.

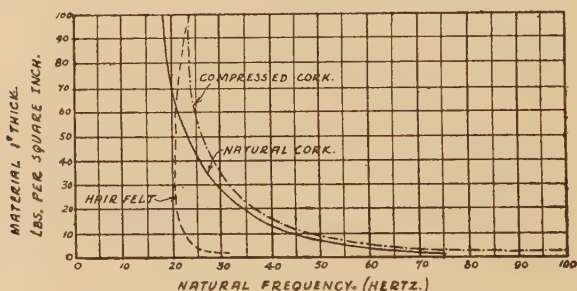
Finally, it is necessary to consider the use of isolation material incorporated in the foundation design. It is an axiom of all vibration work that the natural frequency of the system to be isolated must be lower than the frequency imposed upon it by the incoming vibrations.

Traffic vibrations, as we have seen, usually have frequencies which lie between 9 hertz and 25 hertz. Our present knowledge of the natural frequency under load on the common materials used for isolation purposes is largely based on the work of Messrs. B. E. Eisenhauer and F. G. Tyzzer,⁽⁴⁾ who have given data for cork, compressed cork, felt, asbestos, rubber, &c. These figures are based upon test conditions under static loads.

⁽⁴⁾ B. E. Eisenhauer and F. G. Tyzzer: "Elastic properties of various materials and their effect on the transmission of vibrations." (*Journal of the Franklin Institute*, December, 1932.)

Although the National Physical Laboratory has devised instruments whereby the actual transmissibility of such materials under live loads could be tested, no results have been given in the official literature published by the Laboratory.

If, therefore, we consider the case of natural cork 1 inch thick, it will be seen that its natural frequency becomes lower with the imposition of an increasing load, as shown by the graph below:—



NATURAL FREQUENCY OF MATERIALS UNDER LOAD.

FIG. 4.

The full benefit of cork or any other isolating material used in structural isolation is only derived if the material is heavily loaded. As an instance, under a load of 100 lbs. to the square inch, the natural frequency for a 1-inch thickness of natural cork is about 18 hertz. This may still further be reduced by increasing the thickness of the material to, say, 4 inches, when the natural frequency becomes approximately 9 hertz. Such a low frequency can only be obtained with this very high loading, and it may be pointed out that materials of this nature cannot be expected to support very high loads without changing their physical characteristics.

A case of this kind has been described by Dr. A. H. Davis in connection with one of the acoustical laboratories of the National Physical Laboratory.⁽⁵⁾ The room is mounted on four piers, one at each corner, with a layer of natural cork

⁽⁵⁾ A. H. Davis: *Modern Acoustics*. (G. Bell & Sons, Ltd.)

2½ inches thick between the piers, and the floor of the laboratory. The natural frequency of the room is stated to be reduced to between 20 hertz and 30 hertz, and has the effect of excluding vibrations having a frequency above about 30 hertz. It has been considered necessary to provide for the renewal of the cork insulation by lifting the whole room on hydraulic jacks although the cork is only loaded to some 50 lbs. per square inch.

V. O. Knudsen describes the use of cork isolation against vibration in an acoustical laboratory, but this is subjected to a much lighter load than that at the N.P.L.⁽⁶⁾

It is extremely doubtful whether the resilient materials on the market provide with safety of loading much protection against vibration transmission of very low frequencies when used as structural units. They do, however, provide protection against higher frequencies, and in particular against those in the audible range, and their use in machinery isolation is referred to later.

To summarise the position, the isolation of the structure by constructional design against the traffic vibration should be considered if a vibration survey of the cleared site shows this to be necessary. The amelioration of such trouble when a building is completed is a very difficult matter, and is best tackled at the source, since adequate protection by structural alteration is usually impossible. The re-surfacing of a road or the provision of modern welded rail tracks is, on the other hand, a comparatively simple matter.

In the case of old property, and particularly domestic property, good road conditions are of paramount importance.

MACHINERY ISOLATION.

One of the most important aspects of vibration problems met with by the surveyor in general practice is that which arises in connection with machinery which is situated in buildings. Most machinery in motion gives rise to some form of vibration, and unless steps are taken to isolate

⁽⁶⁾ V. O. Knudsen: *Architectural Acoustics*. (John Wiley & Sons Inc.)

machines from the floors or foundations upon which they stand, there is a likelihood of complaints arising.

It is necessary to refer in a little more detail to the axiom mentioned in a preceding paragraph. This may be simply explained by saying that if a force having a frequency of, say, 50 hertz, is imposed upon a system having a natural frequency of 10 hertz, the low natural frequency of the system will resist the exciting force and very little vibration will be transmitted to the foundation. If, therefore, a machine is separated from its foundation by an elastic medium which will so lower the natural frequency of the whole system that it is well below any disturbing frequency in the machine, the building will be relieved of much of the transmitted vibration.

Reference to the curves shown on Fig. 4 will show that the use of resilient materials will be limited to machines having a fairly high frequency. It can also be demonstrated that the transmissibility of resilient materials when loaded increases as soon as there is an increase in the stiffness of the material.

The principal difficulty encountered when using resilient materials lies in the fact that they introduce an uncertain measure of damping which varies according to the stiffness of the materials under load, and once an installation is complete no adjustment is possible.

Springs, on the other hand, are constant in their stiffness, and the natural frequency of an installation on a spring mounting may be determined by applying the formula $N_e = \frac{300}{\sqrt{f}}$ where N_e is the natural frequency of the installation and f the static deflection of the springs in centimeters. Although the breakage of springs is unlikely to occur under normal conditions, it is possible to meet emergencies of this kind in the case of a properly designed installation. The dynamic forces in machinery may be broadly divided into two main groups—(a) those setting up impact forces, and (b) those setting up oscillatory vibrations.

In the case of (a) the laws of the impact of bodies are aligned to the laws of vibration.

An impact of a press, guillotine or power hammer excites the sub-soil or structure to vibrate at its natural frequency.

Therefore the elastic medium separating the installation from the sub-soil or structure must satisfy the following requirements:—

- (1) It must have a natural frequency below the natural frequency of the sub-soil or structure.
- (2) It must have a natural frequency sufficiently removed from the number of impacts within a given period to avoid resonance.
- (3) It must allow for a certain freedom of movement of the installation in the direction of the impact.

Requirements (1) and (2) are fulfilled by the use of spring mounting in the case of machines having impacts up to 150 per minute. The third point is largely controlled by the use of a massive foundation which ensures reasonable working conditions of the machine.

With oscillatory vibrations, the rule previously given of a low natural frequency to the installation is strictly observed. In all cases emphasis must be made of the importance of avoiding the sphere of resonance. If one of the natural periods of the installation happens to coincide with the frequency of the exciting vibration, the machine when working at this frequency is quite likely to increase the amplitude at every stroke or revolution until eventually disruptive forces are set up. In some cases provision is made where machinery is spring mounted, particularly in the case of rotary machinery, for a special form of damping to come into operation in the range of resonance so that this condition is provided for when the machine is started up.

ISOLATION MATERIALS.

The various materials available for machine installation include cork, felt, rubber cylinders and combinations of cork and felt in layers, and units of rubber vulcanised to steel capable of taking up compressive and tensile forces.

Plates of natural cork framed in steel may be used and can be obtained in thicknesses up to $2\frac{1}{2}$ inches. There is no doubt that of the resilient isolating materials natural cork does provide the most satisfactory form of mounting. A spring isolated foundation is, however, the best for all general purposes. Various types of spring anti-vibrators, or vibro-dampers as they are variously called, are available. All of them consist of a steel or cast-iron housing in which the spring, or springs, are situated, and arrangements are usually made to include some material such as asbestos or cork, which minimises the direct transmission of audible frequencies through the steel. It should be noted that steel is an excellent transmitter of sound, and it is unwise to adopt any isolation device which does not provide some protection against sound transmission if high frequencies are anticipated.

Another important point in connection with this type of mounting is that arrangements are usually made for adjusting the compression in the spring, and so varying the natural frequency without in any way altering the height of the spring unit itself. It is thus possible to meet any unforeseen conditions, should this be necessary.

METHODS OF MOUNTING MACHINERY.

The following are the three principal methods by which machinery may be mounted either upon springs or resilient materials:—

- (a) Directly upon the springs, resilient slab or pads.
- (b) Upon a concrete base with a slab or spring interposed between the base and the floor of the building.
- (c) With the springs incorporated in the concrete slab itself.

The correct design of dynamically loaded foundations is an engineering problem within the province of a specialist, and should always be referred to him if a satisfactory job is to be obtained.

The first type of mounting can be applied to most forms of light machinery, such as electric motors and fans, where the exciting frequency is high and the frame of the machine itself is not likely to become distorted. Wherever such distortion is likely to occur, or where there is direct coupling between, say, the fan and the motor, it is necessary to utilise the second form of mounting.

The concrete slab has in addition another function to perform. In the case of light machinery, or where the revolutions are so low that an additional loading of the springs is necessary to obtain the requisite compression, this slab acts as a loading slab.

For practical approximation the weight of the slab should be at least equal to the weight of the machines which are to be mounted thereon. It is important to see that there is no contact between the isolation slab and the surrounding parts of the building. Where machines are mounted on the ground floor, an air space provides the most effective isolation between the sides of the foundation block. Care must be taken to design such installations so that the centre of gravity of the whole system is correctly positioned in respect of the springs.

The final form of mounting is particularly applicable where a very low natural frequency is required to bring the frequency of the installation below that of the exciting frequency, since long springs are usually necessary, and if these are housed in the thickness of the concrete block, much valuable space is saved. This method has also been used with great success to isolate delicate machinery and instruments such as X-ray apparatus from incoming vibrations such as those set up by power hammers.

In the engineering world there have been many remarkable achievements in the sphere of spring-mounted isolation. The mounting of modern precision machine tools, such as roll-grinding machines which finish the rollers used in foil-making and have to be free from all extraneous vibration, provides one example.

The position of machinery in the building has, of course, a direct bearing upon the effect it will have upon the struc-

ture. Machines mounted in old buildings on wooden floors are a constant source of trouble, and it is usually impossible to apply the methods outlined above to the curing of these troubles until some form of strengthening has been applied to the floors, since the floors of the structure are incapable of withstanding the heavy additional weight of a loading slab. To summarise the position it may be said that the success of machinery installations in buildings is governed by the following factors:—

The machines themselves should be of good pattern ; the modern tendency towards cut prices tends to introduce a cheaper and consequently less vibration-free machine.

Machines using reciprocating parts should, if possible, be avoided, and those in which rotating elements are employed should be used. The dynamic balancing of all rotating parts, or, failing this, the provision of some sort of harmonic balancing apparatus, is desirable.

Machines with heavy frames and base plates should be used in preference to those of the lighter type.

Machinery should, where possible, be installed in the basement, and should in most cases be mounted upon an elastically supported foundation.

Finally, precautions must be taken to ensure that the service pipes, &c., connected to machinery be separated from the actual machine by means of flexible joints.

The author is greatly indebted to Mr. Robert B. Grey, A.M.I.MECH.E., and to Mr. Heinrich, BANG DIP.ING., for their valuable assistance.

He also wishes to acknowledge his further indebtedness to Mr. Grey for the loan of lantern slides illustrating examples of machinery isolation.